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A STRONG-MOTION ACCELEROGRAPH ARRAY WITH TELEPHONE LINE INTERCONNECTIONS

BY

W. O. KEIGHTLEY

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A REPORT ON RESEARCH CONDUCTED UNDER A GRANT FROM THE NATIONAL SCIENCE FOUNDATION

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Mr. William A. Storm, a senior in Electrical Engineering at Montana State University (now with Control Data Corporation), designed and constructed most of the circuitry shown in Figure 8. Mr. David Markwald, a sophomore in Electrical Engineering at Montana State University, helped with the Integrated Circuit Binary Counter circuitry shown in Figure 10. Mr. Rafael Ronderos and Mr. Richard Dielman helped with the testing of the instruments on the five-mile circuit.

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INTRODUCTION

A basic problem in the use of self-triggered strong-motion accelerographs has been the reduction of starting time in the interests of recording as much of the early portion of the record as possible. It has been suggested, for example, that a short memory should be built into the instrument, perhaps by means of a tape loop, so that the very beginning of the ground motion could be recovered. Such expedients have the difficulty of requiring a more complicated, and hence more expensive and perhaps less reliable device.

The system described in Part I below solves this problem by interconnecting for common start several accelerographs distributed over a five-mile region. The interconnection was accomplished using commercial telephone lines. In this way, whichever instrument first receives a ground motion sufficient to start, will also start some of the other instruments a second or so before the strong ground motion arrives. It is believed that in this way the advantage of early starting can be achieved for some instruments without a significant increase in instrument complexity.

Once the interconnection for common start had been made, it was decided to additionally provide a common timing signal to the several recorders so that propagation of seismic disturbances might be studied. Part II of this report describes circuitry which provides common timing and also disconnects recorders from the interconnecting circuit after 8-1/2 minutes of continuous operation. The latter provision prevents exhaustion of film and batteries in the event of a short circuit of the telephone wires. The circuitry for common timing and short circuit protection has not yet been installed on the five-mile circuit, but has been built and tested only in the laboratory, with resistances used to represent the telephone wires.

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Part I. Circuitry for Simultaneous Starting of Several Recorders

A. Description of the Starting Process of the Teledyne RFT-250 Recorder

When the power switch is "on", the RFT-250 Strong Motion Recorder (see Fig. 1(a)) can start in two ways: (1) The ground shakes locally, causing a momentary closing of the seismic switch, (or else the "Test" switch is activated), which through transistorized circuitry activates relay K3, the contacts of which complete the circuit for the coil of relay K2. Contact closure of relay K2 starts the motor, the lamp, and the time pulse generator if the timing module is in "Master" position. An RC circuit holds relay K3 closed, thus maintaining recorder operation, for several seconds after the last contact of the seismic switch. (2) If the terminals "Common" and "Trigger" are connected to like terminals of a distant recorder, and ground shaking at the distant recorder causes its relay K3 to close, then the coil of relay K2 of the local recorder has its circuit completed by an alternate path - out on the line marked "Trigger", through the contact points of the distant relay K3, and back on the line marked "Common", which connects to the negative side of the batteries. In this case the local recorder will stop when relay K3 of the distant recorder opens or if the connection between the recorders is broken.

Thus, the motor, lamp, and timing operate by either the closure of the relay K3 in the local recorder, or by the closure of relay K3 in a distant recorder. Interconnection of several recorders allows each recorder to start and operate as a result of local ground motion and/or as a result of ground motion at any one of the distant interconnected sites. If the interconnecting wires remain intact during an earthquake, all recorders will start and stop at approximately the same time, slight differences being due to variations of applied voltage and mechanical characteristics of the relays K2*. If interconnecting wires break during an earthquake, the recorders will operate as if they were not interconnected.

Interconnection of several recorders reduces the reliability of the recorders operating during an earthquake in two ways: (1) If a high voltage source should be accidentally connected to one or both of the interconnecting wires, the circuitry in the recorders could possibly be destroyed by high currents. (2) If the interconnecting lines should accidentally be short-circuited to each other, all the recorders would run until their batteries were exhausted, and they would not be able to function if an earthquake should occur before the condition was discovered.

An attempt to protect against the first condition is made by inserting a pair of 15-volt, 1-watt Zener diodes, back to back, across the external lines, and 10 ma fuses in the lines, external to the Zeners. Supposedly the Zeners will limit the voltage between Trigger and Common to ± 15 V and the fuses will blow before the Zeners are damaged by large currents. This arrangement worked in several laboratory tests in which 110 V AC was connected directly across a 10 ma fuse in series with a pair of the Zeners. The transient voltage never exceeded 18 volts before the fuses blew. If high currents blow the fuses, the system is

*Differences of up to 0.003 sec. in closure times were noted for new relays, K5, described later, which are more sensitive than the relays K2. In these tests, one relay was activated by 12 volts, while the relay being compared was activated by approximately 6 volts, voltages which might might occur in the case of widely separated recorders.

inoperative as an interconnected system, but each recorder will still function independently.

If the second condition occurs, i.e., the lines are accidentally short-circuited, the condition can be detected by an alarm which is activated by the starting of one of the recorders. The alarm calls an attendant to correct the short circuit and return the recorders to operating condition. The alarm is, of course, activated during an earthquake. It is recommended that a system of recorders interconnected with wires external to a building never be installed without an alarm to indicate a short circuit.

Telephone lines can be used to interconnect recorders over long distances. Where these lines pass through telephone company switchboards they should be direct connected, one to another, without passing through relays or modulating equipment, which would degrade time relationships among recorders. Such lines, consisting of a pair of wires of "telegraph quality", can be rented in Los Angeles, California, for about $4.00/month/mile. The resistance of a line depends on the length and the wire gauge, which varies in different sections of a city, and therefore the resistance cannot be accurately predicted in advance of an installation. In Los Angeles, the maximum resistance from a central office to a termination is 1200 ohms, for a pair of wires shorted at one end, and measured at the other end.

Line resistance of more than a few hundred ohms is sufficient to prevent relay K2 from operating due to closure of a relay K3 in a distant recorder. Relay K2 (Sigma 42 R06-1000-S/SIL), DPDT, has a coil resistance of 1000 ohms and requires 10 volts for operation. Since only 12 volts is available from the batteries, theoretically an external line resistance higher than 200 ohms would prevent operation. A desirable substitute for relay K2 would be a relay which would operate on less than 12 volts, but which would have a high coil resistance so that variations in external line resistance would not have much effect on the voltage across the coil. No substitute for relay K2 could be found, so the solution presented here is to install a more sensitive relay, contact closure of which completes the circuit for relay K2. The new relay, called relay K5 (Sigma No. 5R-5000-S/SIL), has a 5000 ohm coil resistance and needs 5 volts across the coil for operation. This relay will operate with up to 7000 ohms external line resistance*, and it will not overheat when the full 12 volts from the batteries is applied, which would occur when relay K3 of the local recorder closes due to local ground shaking. Figure 1(b) shows the position of the new relay K5 in the circuitry.

Installation of the new relay K5 simply makes a recorder more sensitive to triggering at a distant location. Other operating characteristics are affected in only one other way: reliability of operation is somewhat reduced because operation is now contingent upon the new relay K5 operating, in addition to relay K2 for distant triggering, and upon relays K3, K2, and K5 for local triggering.

B. Detailed Description of Installation of the New Relay K5 into the RFT-250 Strong-Motion Recorder

Materials: 1 ea. Sigma Relay No. 5R-5000-S/SIL in aluminum case; 1 ea. 5-pin socket base to fit relay base; 1 ea. diode 1N2611;

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*If more than one recorder is to be started using the same set of telephone lines, the additional voltage drop caused by the larger currents will limit maximum line resistance to less than 7000 ohms, unless other steps are taken. This situation is discussed later.

1 ea. diode 1N277; 1 ea. 2-terminal micarta strip; 14 inches each of insulated wire, 26-gauge or larger, in colors orange, green, yellow, grey; 1 ea. piece of soft flat steel, 6" long x 1/2" wide, for forming a spring clip; 1 ea. block of foam glass or similar compressible material 1-1/2" x 1" x 2"; soldering pencil, solder, tape.

1. Turn the recorder on its side, front down. Remove bottom cover panel. Unsolder 3 grey wires from upper end of CR1, diode 1N2611, which is mounted on a micarta mounting strip on the right-hand side of the exposed circuitry. (See Figure 2.) Always use a heat shunt on a diode lead to protect the diode from excessive temperature when soldering.

2. Test the relay. It should produce an audible click with as little as 5 volts across its coil. Seal the base of the aluminum can containing the relay by covering openings with tape.

3. Plug the new relay K5 into the new 5-pin socket. Solder the orange wire to pin No. 3 of the relay socket, the green wire to pin No. 4, the yellow wire to pin No. 1, and the grey wire to pin No. 5. Solder the new diode 1N2611 across pins No. 1 and No. 5 of the relay socket, with the arrow on the diode pointing from pin No. 5 to pin No. 1. (A circumferential line on a diode signifies the point of the arrow if the arrowhead is not shown.) Do not bend diode leads closer than 1/8" to the diode itself.

4. Place the relay, base up, in the upper right-hand compartment of the recorder base casting. Remove two screws holding the connector in the compartment below the new relay, then push the new wires through the now exposed grommet into the central base compartment.

5. Cut to length and solder the orange wire to the upper end of CR1 (from which the grey wires were disconnected). Solder the green wire to the ground strap (at top center of circuitry, where many green wires connect to one point). Solder the yellow wire to pin No. 1 on the socket of relay K2. This point is on the large octal base socket at the right-hand side of the circuitry. A 39-ohm resistor (orange, white, black, gold) also connects to this point.

6. Mount the new 2-terminal micarta strip on the inside of the front face of the recorder. Use one of the screws which hold the black terminal block to the front of the recorder. Solder the new diode 1N277 across the terminal strip, with the arrow pointing up (to the inside of the recorder). Solder the grey wire from the new relay K5 to the lower end of the terminal strip. Connect a grey wire from the upper end of the terminal strip to the exposed ends of the three grey wires disconnected earlier. Tape over the exposed joint.

7. Tie the new wires onto existing groups of wires. Wrap wires leading from relay K5 with tape where they pass over the rib of the recorder base casting. Make a spring clip to fit over the rib in the base casting in order to support relay K5 when the recorder is righted. Wedge the piece of foam glass on the right side of relay K5.

8. Replace the bottom cover panel, turn the recorder right side up and test its operation.

C. Connections for Activating an External Alarm

Connections for activating an external alarm to indicate that the array of recorders has been triggered (either by an earthquake or by a short circuit in the interconnecting wires, or by a spurious signal) are most easily made on a model of the RFT-250 which has an Amphenol connector No. 57-40140 mounted in the base casting, intended for interconnecting recorders via radio. In this case it is necessary to make only one connection in the circuitry beneath the base of the recorder - connect a red wire from pin No. 2 of relay K4 (a source of +12 V when power is "on") to pin No. 6 of relay K4 (R400-3-C-1K, Electronic Specialty Company, in a grey sealed case). Then wire the latching relay, which completes the circuit for the alarm, as shown in Figure 3, and connect it to the recorder using an Amphenol No. 57-30140 plug.

A momentary closure of the timing relay K4 closes the new latching relay, activating the alarm. In addition, upon latching in the alarm status, the relay disconnects itself from the recorder's battery, and draws no power after the first closure of the points of K4. (The latter provision is optional, and simple rewiring in the relay box will provide voltage to close the relay every time the points of relay K4 close.) Pushing the "reset" button shuts off the alarm and resets the latching relay for further action. The alarm can be disconnected by the manual toggle switch when recorder tests are made.

D. An Array of Strong-Motion Recorders Interconnected between Millikan Library-Seismological Lab-JPL

An array of five RFT-250 strong-motion recorders, distributed among three sites, was installed at the California Institute of Technology in August, 1969. Figure 4 is a schematic drawing of the installation. The resistances shown for the telephone wires interconnecting the sites were measured with a Simpson volt-ohmmeter, when the wires were temporarily short circuited at the terminations. At Millikan Library and at JPL the recorders on the roofs receive timing signals from the recorders in the respective basements through third "Time" wires (not shown in Figure 4) which have been installed in the buildings.

Study of Figure 4 shows that the electric currents in the various branches of the circuit will vary, depending on which recorder has been triggered by ground motion. The case shown, in which the relay K3 of recorder No. 3 has been closed by local ground motion, is the most critical. Here the voltage drop in the 800 Ω segment is caused by the operation of four recorders, and the voltage drop in the 1200 Ω segment is due to the operation of two recorders. Actually, five simultaneous circuit equations involving the five unknown currents and the five known battery voltages could be written and solved for the currents and the voltage drops in the line segments for all the various combinations of recorders triggered by ground motion. A simple approximation, however, which is not conservative, and which might indicate that the circuit would work when actually it would not work, is to assume that each recorder requires 1.0 ma for operation, and to compute the voltage drops on this basis. Using this assumption, the recorders at JPL would experience 2.4 volts drop in the 1200 segment, plus 3.2 volts drop in the 800 segment, plus about 0.9 volts drop in the fuses*, for a total of 6.5 volts drop outside the coil of relay K5, which itself causes a drop of 5.0 volts when drawing 1.0 ma. When these voltage drops are added, together with the 0.3 volt drop in the diode 1N277 (which prevents high voltage batteries from

*Some tests of a 10 ma Littlefuse revealed the following: The fuse carried 14 ma for about two minutes before burning out. The resistance of the fuse was 180 Ω when carrying 1 ma or 4 ma, but it was 250 Ω when carrying 8 ma. Heating apparently causes a significant increase in resistance at higher currents.

discharging back through low voltage batteries), the total is 11.8 volts.

Terminal voltage of the RFT-250 batteries drops by approximately 0.5 volts from the open circuit voltage when the recorder is operating. It would appear that the line drops described above are almost enough to prevent the recorders in JPL from operating. It is found, however, that while the relays K5 require 5 volts to close their points, once closed they will remain closed until the voltage across the coil drops to about 3 volts, so the battery voltage drop which occurs when a recorder's motor and lamp start does not cause relay K5 to open. In practice, it was found that as much as 700 Ω extra resistance could be inserted in the line connecting to the Seismological Laboratory, and all recorders would still start when no-load battery terminal voltages were as low as 12.5 volts. In this situation of marginal starting due to extra high line resistance, it is possible that one or more recorders do not start until others have started, the operating voltage drops of the latter being just enough to reduce their telephone line currents to the point where the other recorders can start.

In case line resistance is too high, or the number of recorders in an array is too great for the relays K5 to operate on remote triggering, more voltage needs to be applied to increase the currents carried by the telephone lines. Figure 5 shows a possible method of doing this. The new batteries at each recorder are effective only when the local relay K3 is closed by local ground motion. Voltages driving the telephone lines could possibly be increased to 100 volts, the limit being determined by overheating of relay K5 when the full voltage of the new battery is applied across K5 when relay K3 is closed by local ground motion. Other solutions are possible, involving new relays and diodes, in which the voltage across relay K5 never exceeds 12 volts. (The Pacific Telephone Company does not permit more than 120 V D. C. across its lines.)

E. Instructions for Inspecting the RFT-250 Array between Millikan Library, Seismological Lab and JPL

1. The triggering of any recorder in the array will activate the alarm in the Minneapolis-Honeywell Select-a-Code monitoring panel in the campus Heating Plant, California at Wilson, unless the recorder is disconnected from the array, or the alarm is disconnected with the switch in the Alarm Reset Box adjacent to the recorder in the basement of Millikan Library. It is suggested that the alarm be tested, and not shut off, but that the panel operator in the Heating Plant be called (Ext. 1730) and informed that tests will be made over the next few hours.

2. Use the Data Log (Table No. 2) to make a record of tests and maintenance.

3. Note the reading on the counter when you arrive, and verify that it agrees with the reading predicted after the last visit to the array.

4. Open the aluminum Disconnect switch box and turn the Disconnect switch "off", so that running the recorder will not trigger other recorders in the array.

5. Connect the voltmeter leads between "+12V" and "Common" terminals on the front of the recorder. Read the voltage when the recorder is not operating, short between "Trigger" and "Common" terminals to start the recorder and read the voltage again. If new batteries are to be installed, repeat the tests on the new batteries.

(Because of the extra current required, for the counters, and for the alarm relay in Millikan Library, the recorders in this array should be equipped with 2-ampere fuses. Don't forget to verify the size of the fuse if a new battery pack is installed.)

6. With the ohmmeter on a high resistance setting, test the continuity of the 10 ma fuse in the Disconnect switch box by measuring its resistance in series with the resistor soldered to the fuse mounting clip. A direct measurement of only the fuse resistance, without the resistor in series, will burn out the fuse. Only one fuse is used at all installations to keep circuit resistance to a minimum.

7. Disconnect the orange Trigger wire from the front of the recorder, then connect a meter of microamperes sensitivity in series between the Trigger terminal and the orange wire. Read the local current drain through the Zener diodes in the Disconnect switch box. Turn the Disconnect switch in the aluminum box "on" and again read the current drain. If the local drain is more than $10\mu a$, the Zener diode whose arrow points from Trigger to Common should be replaced by one which has been tested to have acceptable leakage. Drain of the array with the Disconnect switch "on" should not be more than $10\mu a$.

8. Reconnect the orange Trigger wire to the Trigger terminal. Turn the Disconnect switch "off" and perform other tests on the recorder - checking the trace alignment, frequency of timing signal, starter pendulum setting, etc.

9. After the recorder cover has been replaced and latched and exposed film has been run into the take-up magazine, turn the

Disconnect switch "on" and test the triggering of the other recorders in the array by triggering the local recorder with the Test Switch. On the data sheet, change the expected readings of the counters on the other recorders to account for this latest triggering, reset the local counter and the Action Indicator, and fasten on the cover of the Disconnect switch box with screws.

10. Visit installation No. 1 last, in the basement of Millikan Library, and reset the relay which controls the alarm in the Heating Plant. Call the panel operator in the Heating Plant, Ext. 1730, and inform him that your tests are finished.

Part II. Synchronized Timing of Several Recorders Interconnected via Telephone Lines

The circuitry shown in Figure 6 will send timing pulses from a Master recorder over telephone lines to provide synchronized timing in Slave recorders. This requires at the Master recorder only the addition of a diode (germanium suggested to minimize voltage drop) in series with the points of relay K3, and a new 6-volt battery connected across the telephone lines, switched in and out of the circuit by points (pins No. 5 and 6) of the timing relay K4 which are not ordinarily used.*

The new 6-volt battery provides negative voltage pulses on the telephone lines, below the ordinary operating voltage levels, when timing relay K4 closes in the Master recorder. The new diode prevents this battery from short circuiting when both relays K3 and K4 are closed. Pulses observed at Slave recorders in the system linking the campus, JPL, and the Seismological Laboratory vary from 0.180 V to 12 V below DC levels, which themselves vary, depending on the combination of recorders triggered by local ground motion. The timing pulses do not decrease the currents through the coils of starting relays K5, and hence do not degrade simultaneous starting.

A. Circuitry in Slave Recorders

The general scheme for utilizing transmitted pulses in Slave recorders is shown in Figure 7, the detailed circuitry in Figure 8. Figure 12 and Table 1 show the color code scheme for wires interconnecting

*If an alarm is also to be activated at the Master recorder, it can be powered by connecting to pin No. 3 of relay K2, instead of pin No. 5 of relay K4.

elements at a recording station. The DC component of the pulses is removed by capacitive coupling, and the negative leading edges of the pulses turn off transistor Q_3, producing positive 6V pulses at point A. These pulses, through transistors Q_4, Q_5, Q_6, drive the timing galvanometers of the recorders in one building if the latching relay K6 is in normal position. Transistor Q_6 can dissipate 0.8 watt, so five galvanometers can easily be driven. Zener diodes and a fuse protect this circuitry from high voltages on the telephone lines.

The circuitry between Q_0 and the unijunction TIS43 will produce short positive pulses about every three seconds unless a positive 6V pulse appears at point A during this period. Failure of the pulses from the Master recorder therefore results in a pulse from the unijunction which turns on Q_1, activating latching relay K6, which then connects the local timing pulse generator to the timing galvanometers. If relay K6 switches due to failure of pulses from the Master recorder, it can be restored to normal position by pushing the "Time Reset" button. Zero resistance between a pair of external test points indicates that the relay should be reset if timing is to be synchronized over the telephone lines.

The timing mode switch must be in the "Master" position in the Slave recorder which is in the lower story of a building. The timing relay K4 in this recorder operates when the recorder runs, but it does not drive the timing galvanometers as long as pulses are received from the Master recorder. Time mode switches on recorders in upper stories should be set in the "Slave" position. Galvanometers in these recorders are driven by pulses from either a distant Master recorder, or the recorder in the lower story.

B. Circuitry for Disconnect after 8-1/2 Minutes' Operation

If the telephone lines should be short circuited, all the recorders would run until their film and batteries were exhausted. An external alarm would call attention that the lines should be repaired and the recorders replenished, but the recorders would be inoperable, even as independent units, until they could be serviced, possibly a period of several days. A scheme for disconnecting the recorders from the telephone lines after 8-1/2 minutes' operation, thus permitting independent operation thereafter, is shown in Figure 9. The details of the circuitry are shown in Figure 10(a). This circuitry is for Master recorders and Slave recorders in lower stories, which control the timing of other Slave recorders.

Pulses from the timing pulse generator, which always operates when one of these recorders runs, are counted by a series of three 4-bit Integrated Circuit binary counters, which on the 1024th count produce a pulse which turns on transistor Q_7, causing latching relay K7 to disconnect the recorder from the telephone lines. Zero resistance across a pair of external test points indicates that the relay has been thrown and that the "Connect Reset" button should be pushed to reconnect the recorder to the telephone circuit.

The counters require a nominal 5V power supply, which is provided by the resistor and Zener diode, shown in Figure 10(a). The counters reset themselves whenever their power is interrupted, so a series of short operations, due perhaps to several earthquakes, would not disconnect the recorders, even though the total operating time exceeded 8-1/2 minutes.

C. Circuitry for Deleting Every 16th Pulse in the Master Recorder

When a seismogram made by a Slave recorder contains timing pulses generated by a Master recorder, distinguishing marks other than the twice-per-second timing pulses are necessary if the Slave's seismogram is to be aligned in time with the Master's seismogram. This is because of the possibility of the loss of a pulse or two at a Slave recorder when voltage levels on the telephone lines vary over a wide range as the relays K3 of the different recorders close due to local ground motion. The deletion of every 16th pulse produced by the Master recorder is satisfactory for identifying the same instant in time on both records.

The general scheme for deleting every 16th pulse is shown in Figure 11, and the detailed circuitry is shown in Figure 10(b). If the 8-1/2 - minute disconnect circuitry is installed, the first counter in that group of three counters can be used to activate an AND gate which produces a positive voltage during every 16th pulse. (Otherwise a single counter, connected as counter No. 1, can be used.) This voltage turns on transistor Q_9, which turns off Q_{10}, preventing relay K4 from closing, and preventing the 16th pulse from appearing. A normally closed relay could be substituted for Q_{10}. The coil of the relay should be placed in the collector circuit of Q_9 in place of the 15K resistor, the 3K resistor in the emitter circuit removed, and a few hundred ohms placed in the base circuit. Although only an SPDT relay would be necessary, the same relay used for K2, Sigma 42R06-1000-S/SIL, DPDT, would be satisfactory. If a different relay is used, a resistor in the emitter circuit of Q_9 might be necessary to prevent the relay from operating on the logical zero voltage from the AND gate.

<u>Summary of Changes Within Recorders Which Would Affect Their Normal Operation When Not Connected to Synchronizing Circuitry</u>

1. <u>Master Recorder</u>. A switch which erases every 16th pulse has been inserted between pin No. 3 of relay K4 (yellow wire) and pin No. 9 of the timing pulse generator (purple wire). The connection between these pins must be restored for normal operation.

2. <u>Slave Recorder.</u> A latching switch has been inserted between the hot terminal of the Slave's timing galvanometer (white wire) and pin No. 1 of relay K4 (black wire). Connection between these points must be restored for normal operation.

   No changes have been made to secondary Slave recorders (located in upper stories).

3. <u>Master and Slave Recorders</u>. A latching switch has been inserted between the manual disconnect switch (orange wire) in the telephone lines and the 10 ma fuse (red wire). The switch opens after the recorder has run continuously for 8-1/2 minutes. To restore continuity, the "Connect Reset" button must be pushed. This switch has no effect on the operation of recorders interconnected within buildings, but not connected to telephone lines. For simultaneous starting via telephone lines, but without synchronized timing, the connection between the manual disconnect switch and the 10 ma fuse must be restored.

   No changes have been made to secondary Slave recorders (in upper stories).

4. <u>Emergency Restoration of Recorders to Normal Operation</u>

Disconnect the box containing the synchronizing circuitry from the wires coming from the recorder and from the manual disconnect box. Connect the yellow wire (Master only) to the purple wire, the white wires to the black wire (Slave only), and the red wire to the orange wire. Cover all exposed conductors with tape. The recorders will now operate singly, interconnected within buildings, or interconnected on telephone lines for simultaneous starting, but without synchronized timing or disconnect after 8-1/2 minutes of operation.

TABLE I. Color Scheme for Exposed Wires

1. Source of Constant +12V (through power switch) - BLUE
   (for resetting latching relays K6 and K7)

2. Ground (to ground strap) - GREEN

3. Source of +12V When Recorder is Running (to pin No. 3 of relay K2) - BROWN
   (power for everything except relay reset coils)

4. Hot Terminal of Timing Galvanometer (Slave only) - WHITE
   (connects to armature of latching relay K6)

5. Lead to Pin No. 1 of Timing Relay K4 (Slave only) - BLACK
   (connects to contact of latching relay K6)

6. Lead to Pin No. 9 of Timing Pulse Generator - PURPLE
   (source of pulses to drive counters)

7. Lead to Pin No. 3 of Relay K4 (Master only) - YELLOW
   (erases every 16th pulse)

8. Lead to Pin No. 5 of Timing Relay K4 (Master only) - GRAY
   (switches new 6V battery in and out of circuit, connects to positive side of new 6V battery)

9. Lead from Telephone Line Side of Fuse F1 - RED
   (time signal to Slave recorder, and connects to relay K7 in Master and Slave)

10. Lead from Recorder Side of Manual Disconnect Switch - ORANGE
    (connects to armature of relay K7)

11. Lead from Recorder Side of Fuse F1 (Master only) - CLEAR
    (connects to negative side of new 6V battery)

12. Wires for Activating External Alarm - COLORS AS SHOWN IN FIGURE 3. Bundle these
    wires separate from other wires.

13. Lead from Slave Synchronizing Box to "Time" Wire to Upper Story - WHITE
    (connects to armature of relay K6)

TABLE 2 SUGGESTED DATA LOG

CAMPUS - SEISMO.LAB. - J.P.L. STRONG-MOTION ACCELEROGRAPH ARRAY

DATE	VOLTMETER No.	ACCELEROGRAPH No.	COUNTER ON ARRIVAL	OLD BATTERIES			NEW BATTERIES			10 ma. FUSE TEST	LEAKAGE CIRCUIT OFF	LEAKAGE CIRCUIT ON	COUNTER NEXT VISIT	REMARKS
				SERIAL No.	VOLTS OFF	VOLTS RUNNING	SERIAL No.	VOLTS OFF	VOLTS RUNNING					

List of Figures

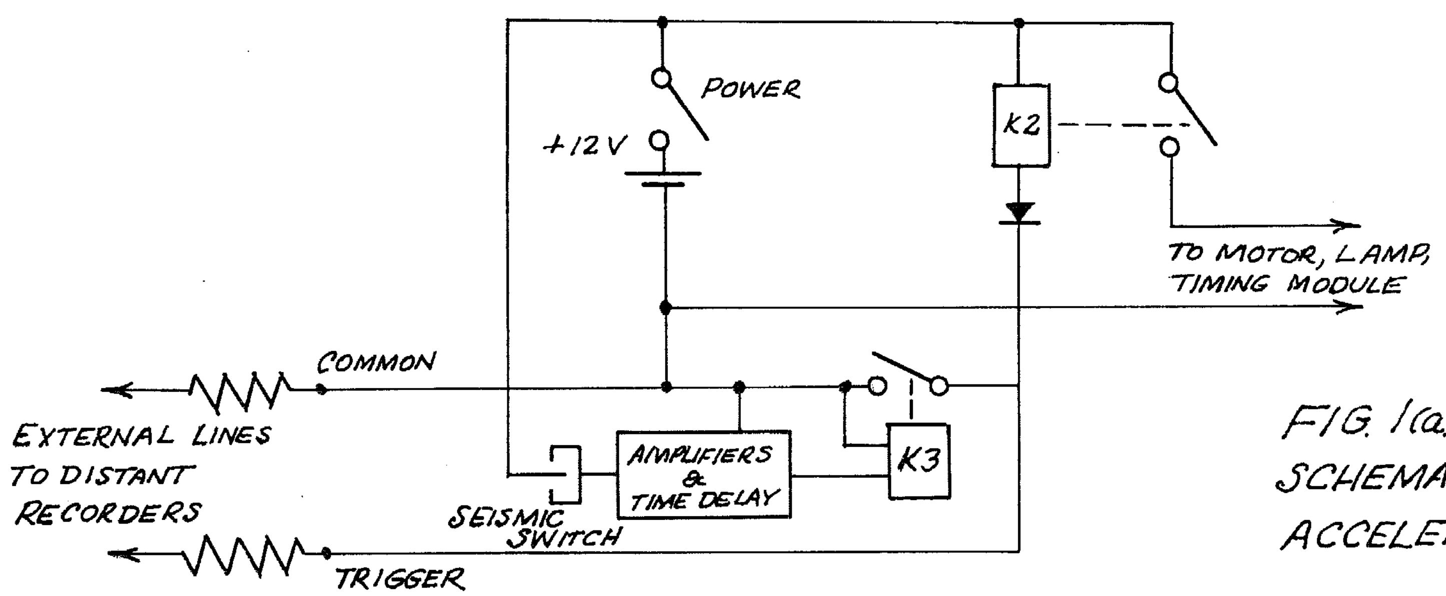


FIG. 1(a) SIMPLIFIED SCHEMATIC OF RFT-250 ACCELEROGRAPH

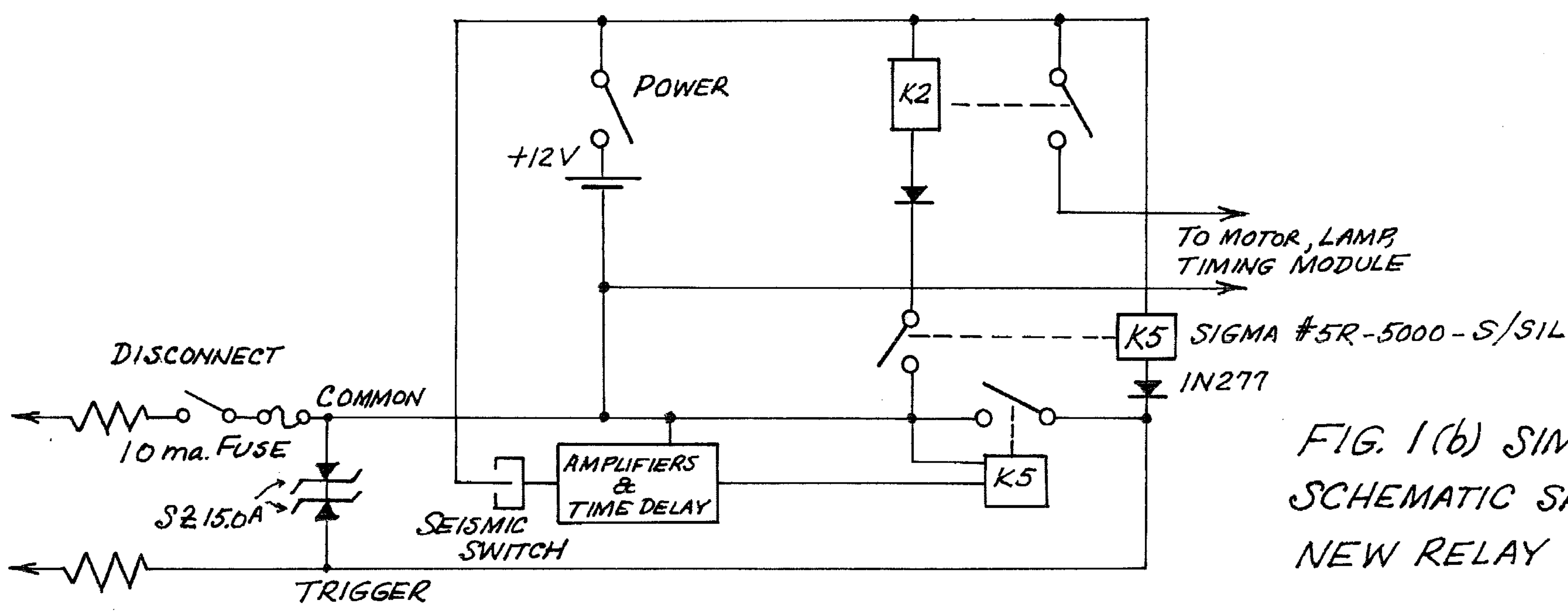


FIG. 1(b) SIMPLIFIED SCHEMATIC SHOWING NEW RELAY K5

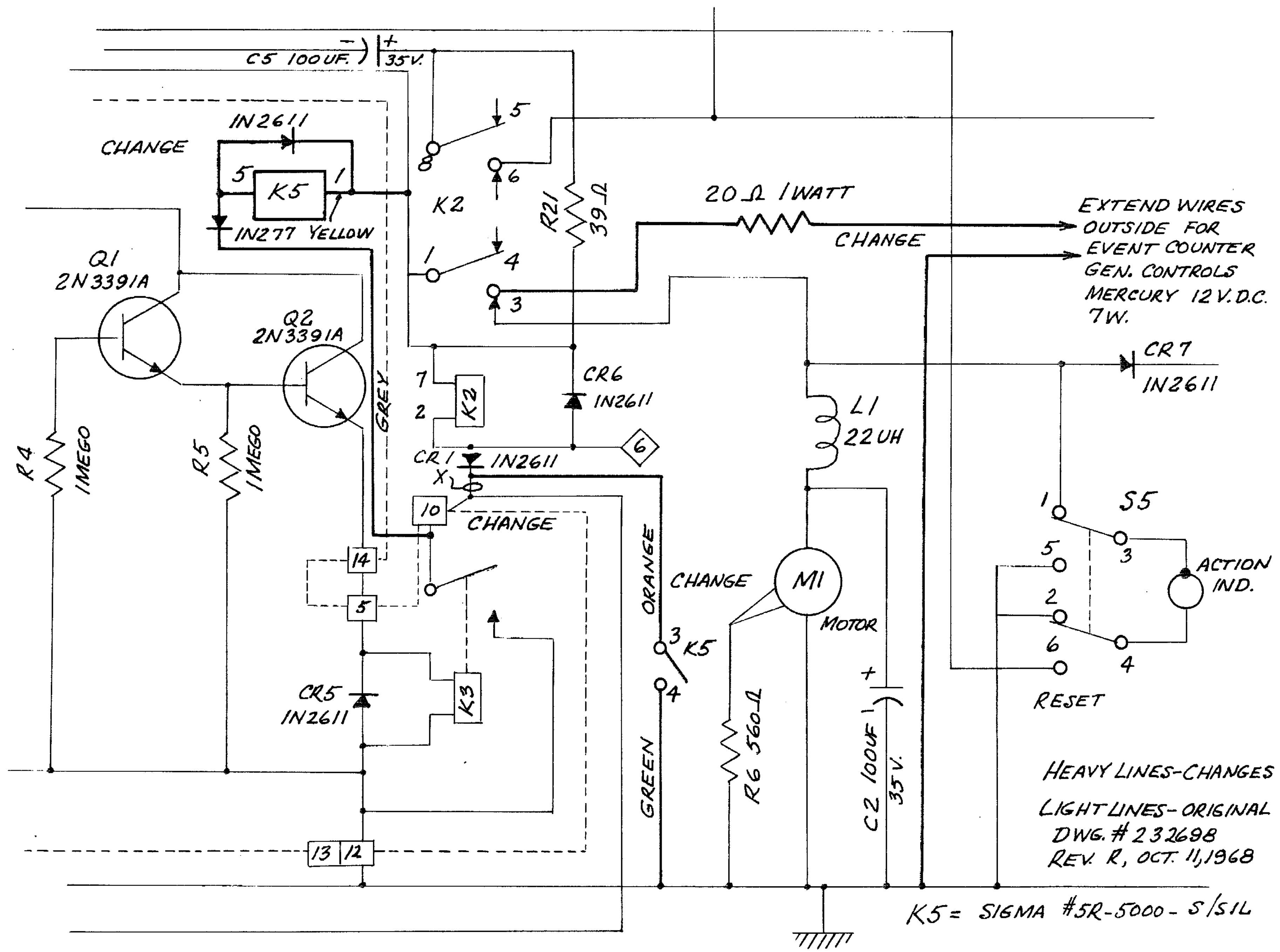


FIG. 2(a) WIRING CHANGES FOR K5 RELAY IN RFT-250 ACCELEROGRAPH

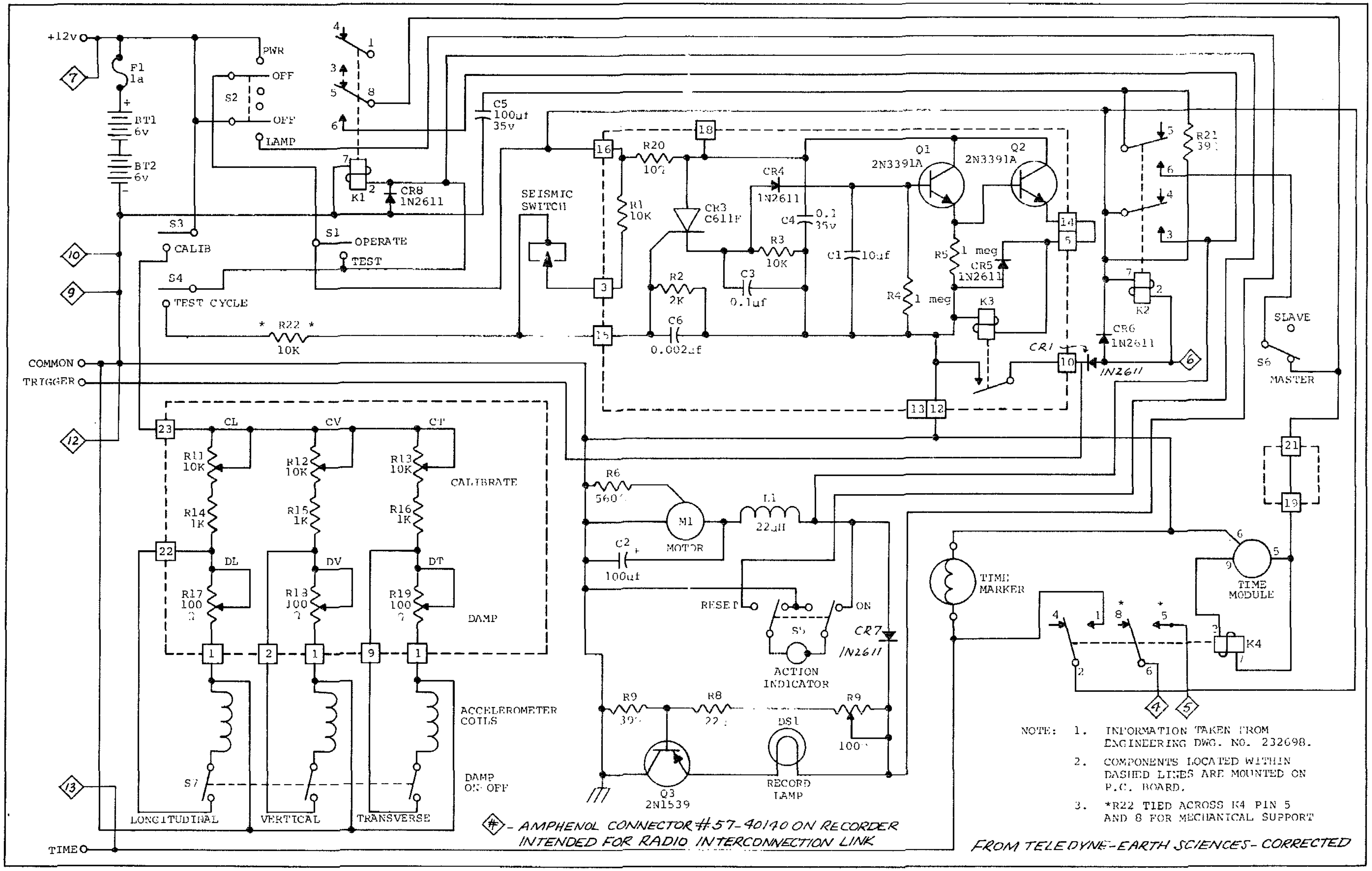
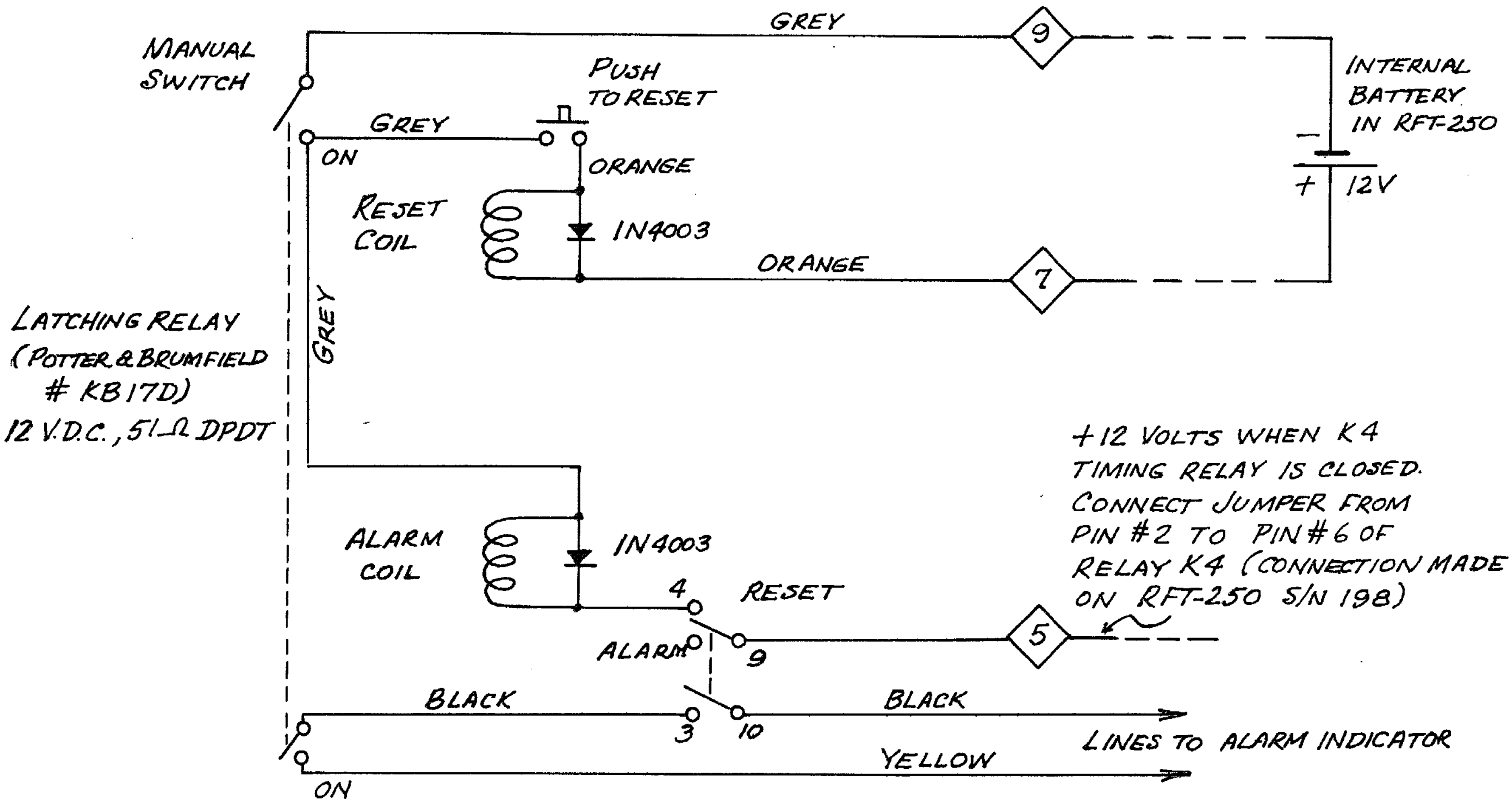


FIG. 2(b) SCHEMATIC OF RFT-250 ACCELEROGRAPH



◇# – REFERS TO PIN ON AMPHENOL CONNECTOR #57-40140 MOUNTED ON BOTTOM OF BASE OF RFT-250. CONNECTOR ORIGINALLY INTENDED FOR LINKAGE OF RECORDERS VIA RADIO. USE AMPHENOL #57-30140 PLUG TO MATE

FIG. 3 RELAY CONNECTIONS TO ACTIVATE OPERATION ALARM

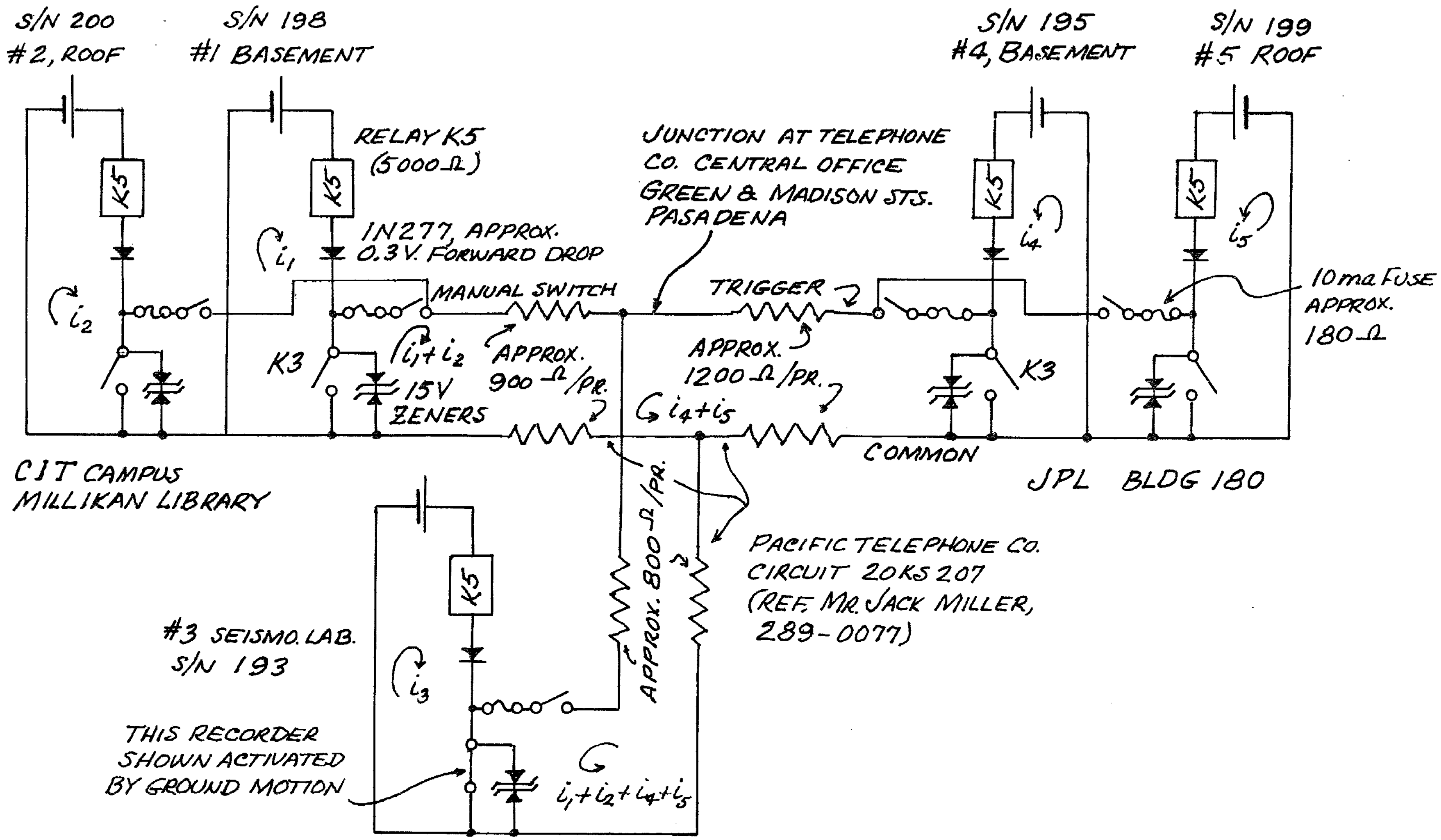


FIG. 4 SIMPLIFIED SCHEMATIC OF CAMPUS-SEISMO LAB-JPL STRONG MOTION RFT-250 ARRAY

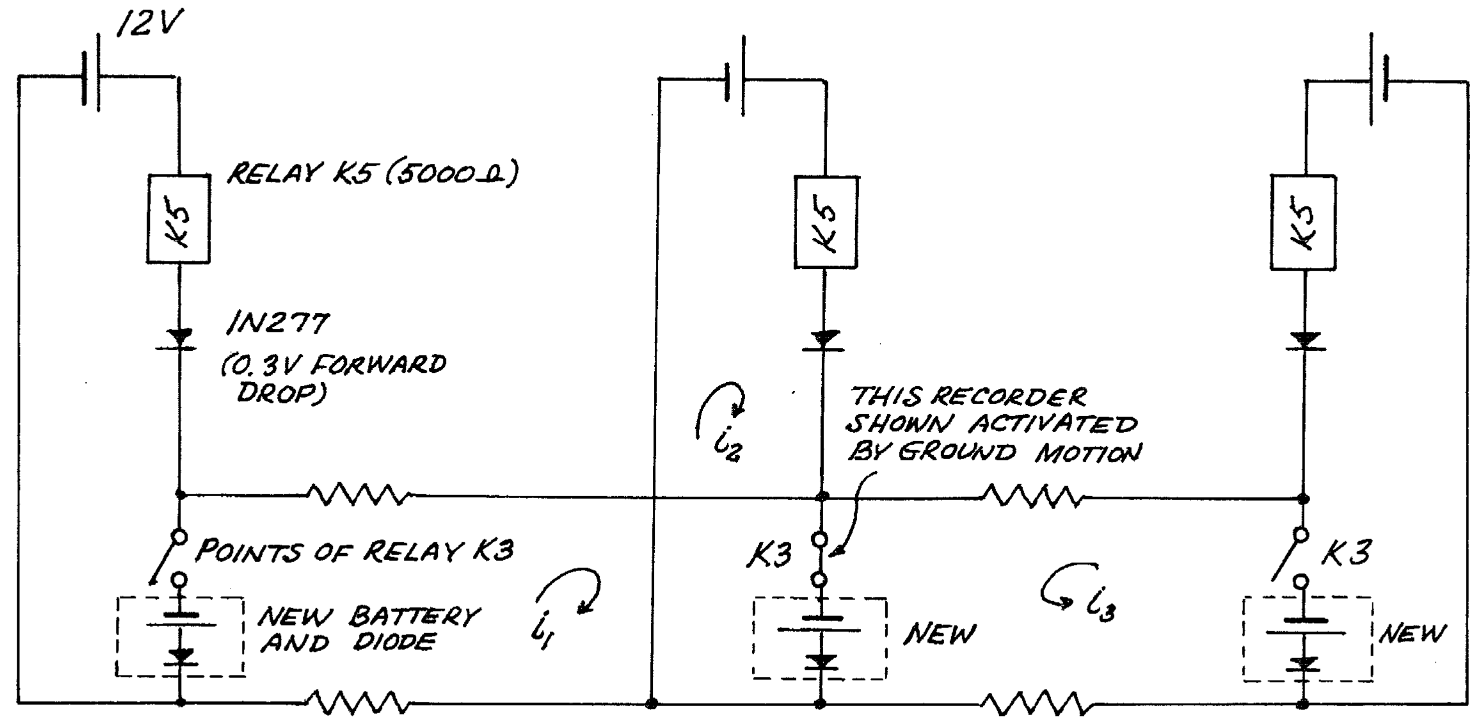


FIG. 5 POSSIBLE SCHEME FOR INTERCONNECTING RECORDERS WHEN LINE RESISTANCE IS HIGH

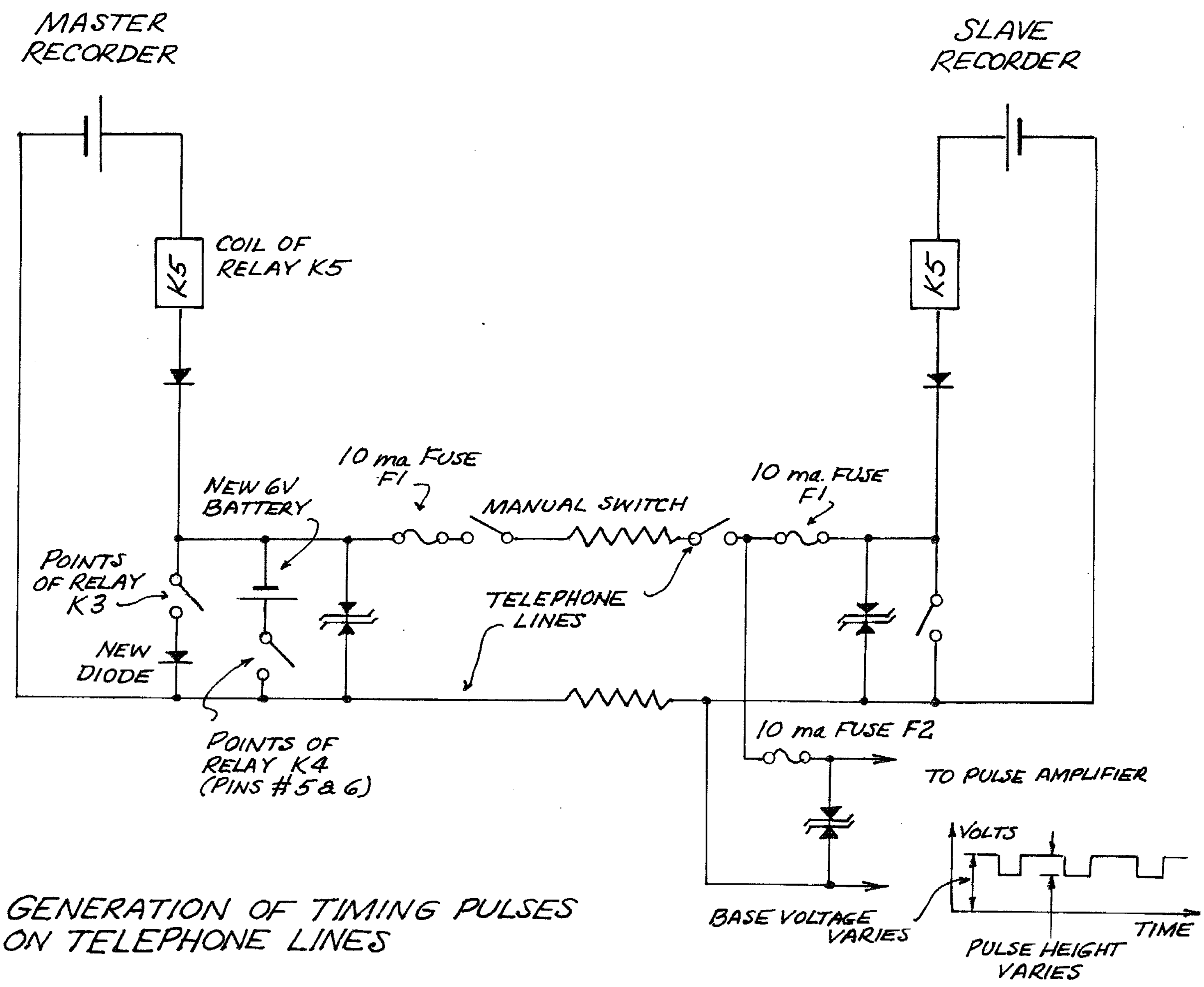
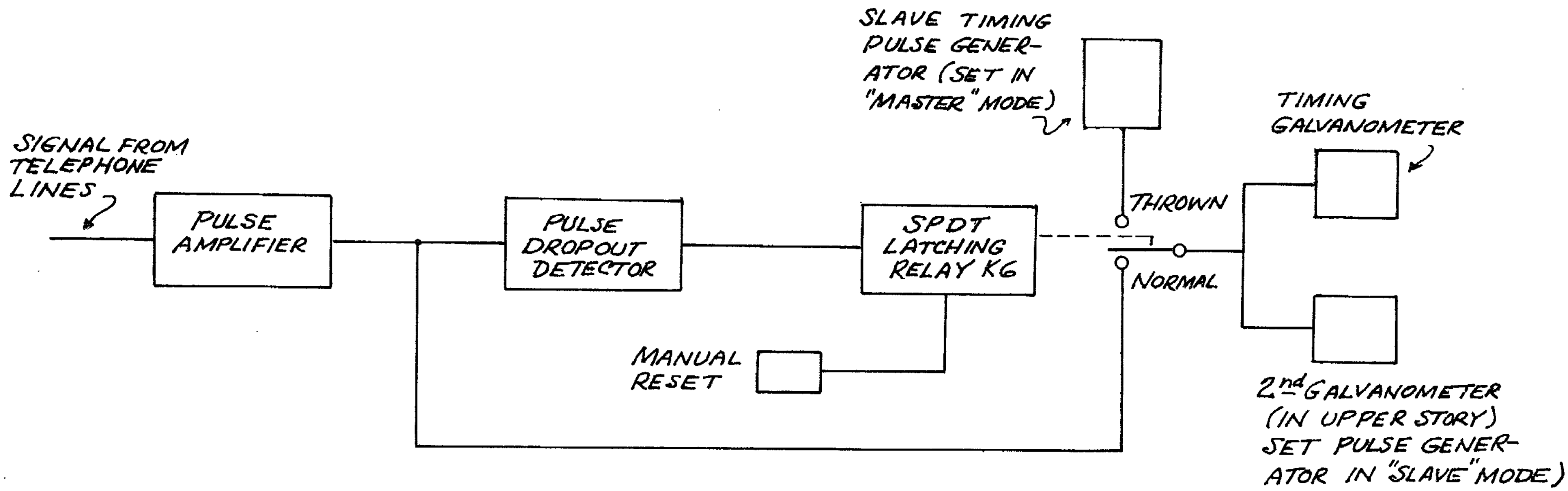


FIG. 6 GENERATION OF TIMING PULSES ON TELEPHONE LINES



ONE DEVICE NEEDED IN EACH BUILDING IN WHICH SLAVE RECORDERS ARE LOCATED. OPERATION: PULSES FROM MASTER RECORDER ARE AMPLIFIED TO DRIVE SLAVE TIMING GALVANOMETERS. IF SLAVE IS RUNNING, AND NO PULSES ARE RECEIVED FOR 3 SECONDS, DEVICE SWITCHES SO THAT SLAVE'S TIMING PULSE GENERATOR DRIVES SLAVE'S GALVANOMETERS.

FIG. 7 SCHEME FOR UTILIZING PULSES IN SLAVE RECORDER

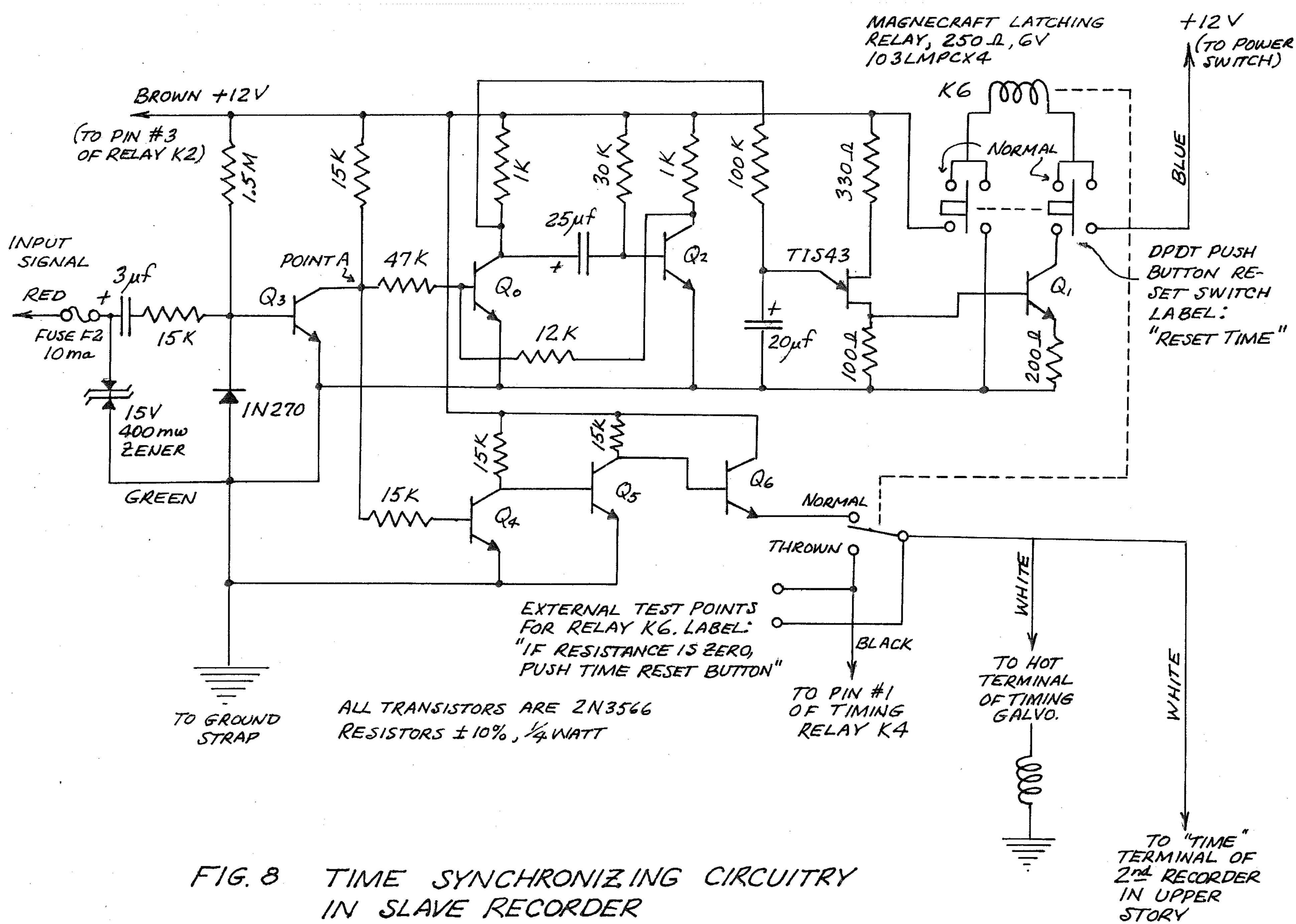
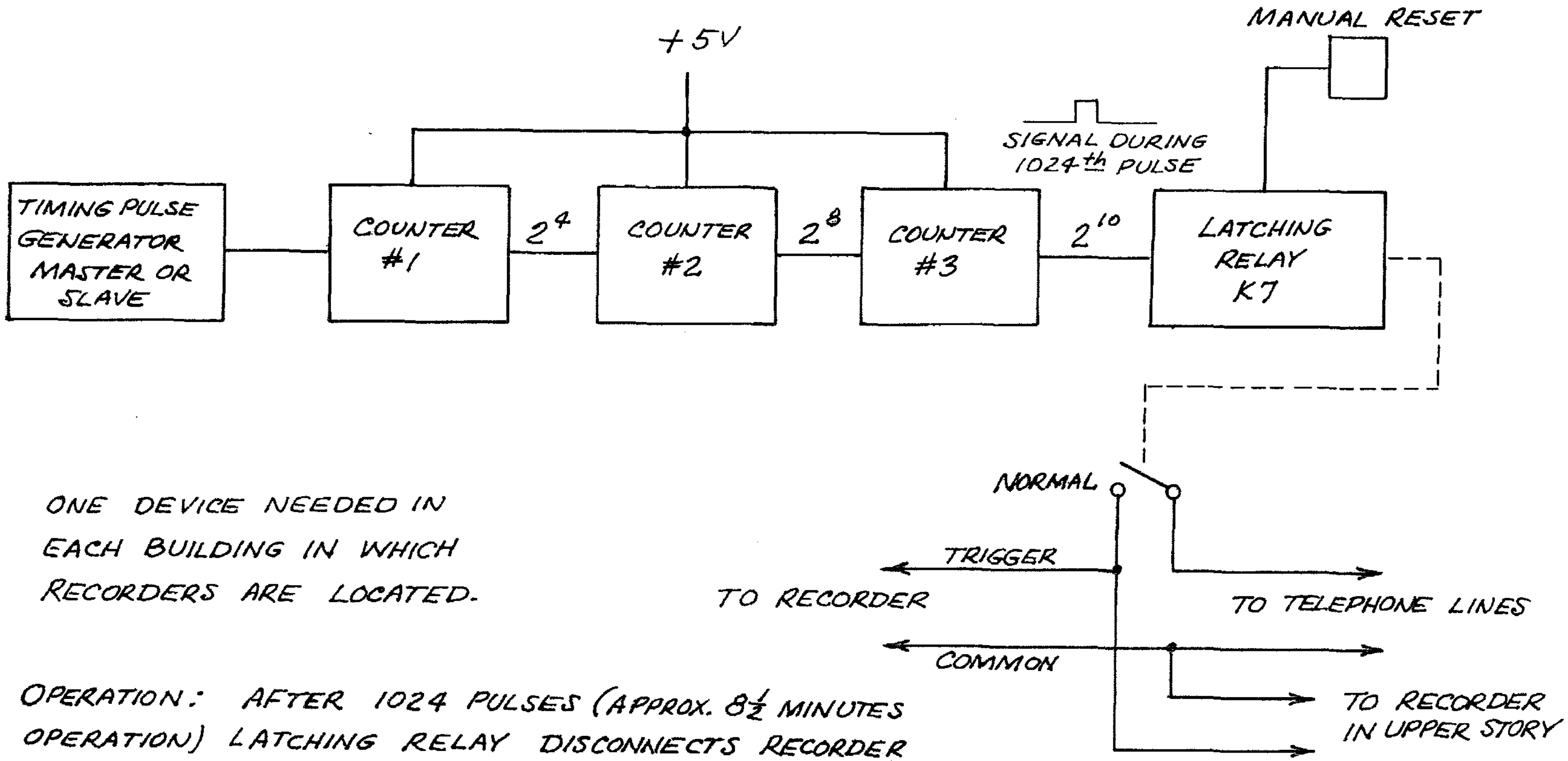


FIG. 8 TIME SYNCHRONIZING CIRCUITRY IN SLAVE RECORDER



ONE DEVICE NEEDED IN EACH BUILDING IN WHICH RECORDERS ARE LOCATED.

OPERATION: AFTER 1024 PULSES (APPROX. $8\frac{1}{2}$ MINUTES OPERATION) LATCHING RELAY DISCONNECTS RECORDER FROM TELEPHONE LINES. CONNECTION IS RESTORED BY MANUAL RESET. COUNTERS AUTOMATICALLY START AT ZERO EACH TIME RECORDER STARTS.

FIG. 9 SCHEME FOR DISCONNECT AFTER $8\frac{1}{2}$ MINUTES OPERATION

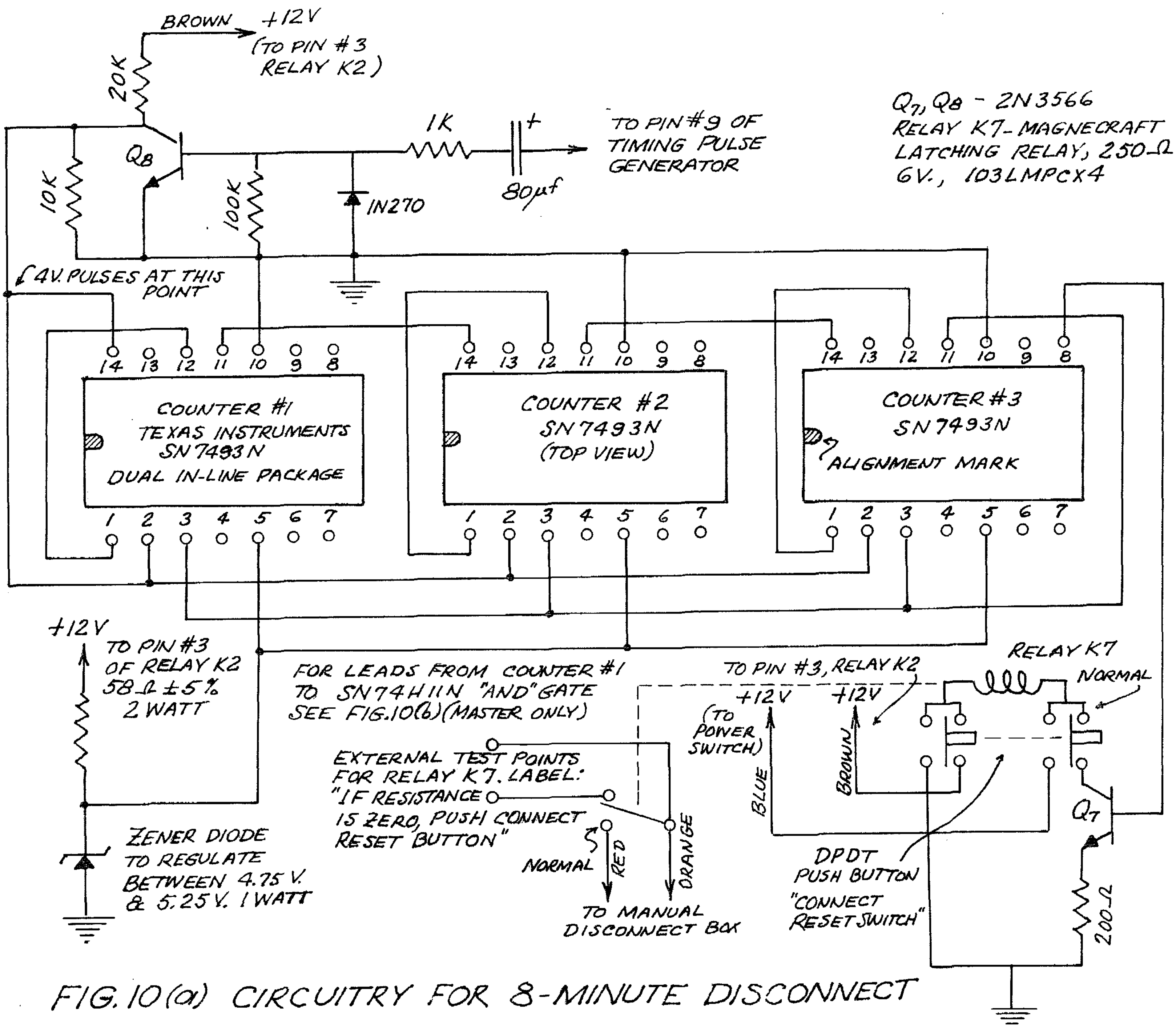
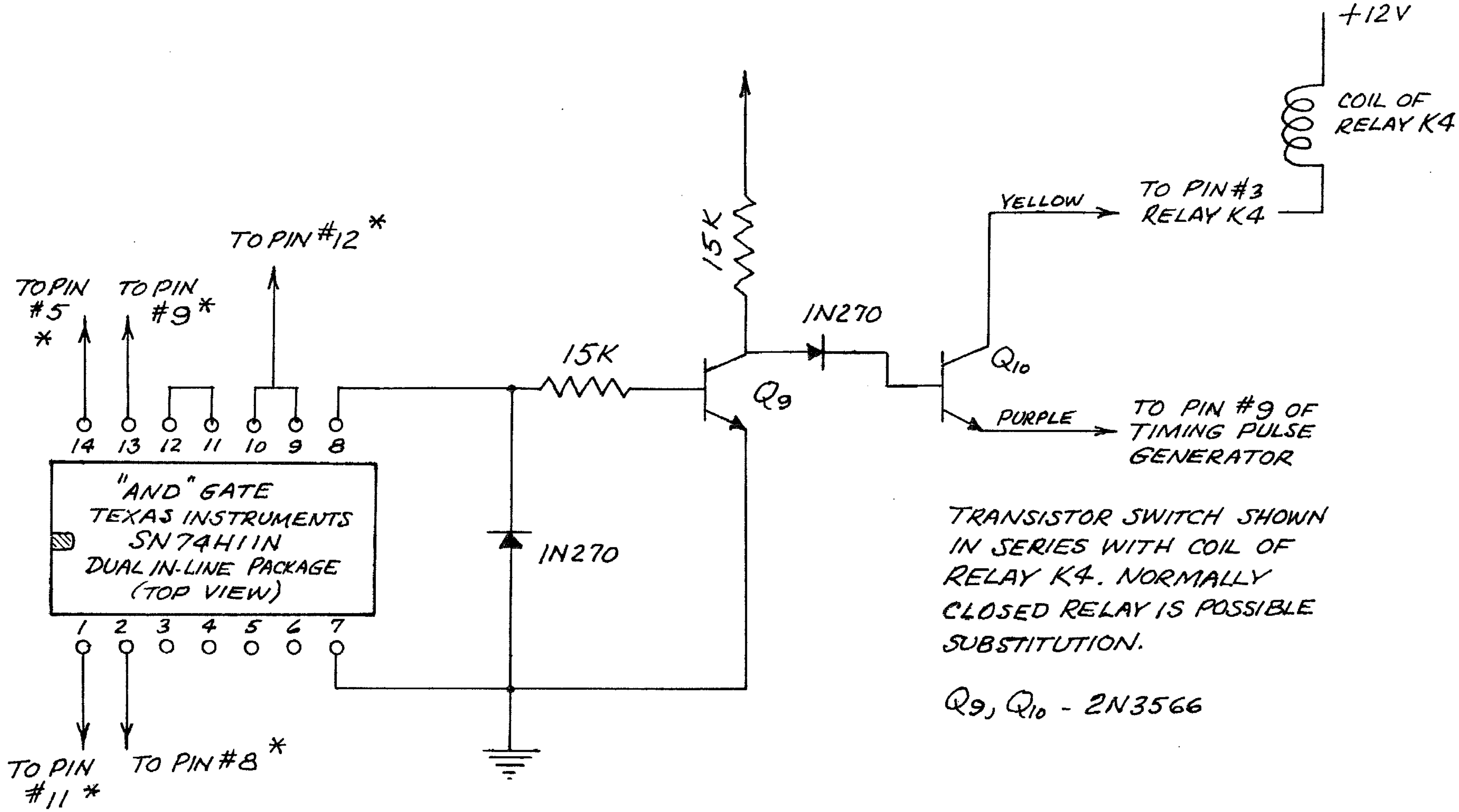


FIG. 10(a) CIRCUITRY FOR 8-MINUTE DISCONNECT

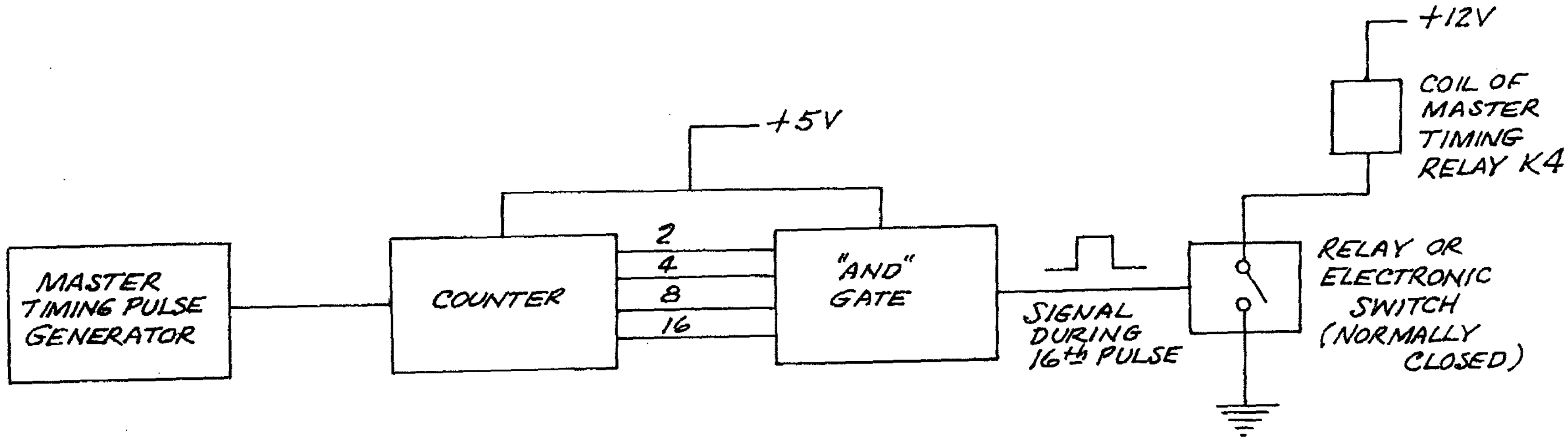


TRANSISTOR SWITCH SHOWN IN SERIES WITH COIL OF RELAY K4. NORMALLY CLOSED RELAY IS POSSIBLE SUBSTITUTION.

Q_9, Q_{10} - 2N3566

* CONNECTIONS SHOWN TO PINS OF COUNTER #1 SEE FIG. 10(a)

FIG. 10(b) CIRCUITRY FOR ERASING EVERY 16th PULSE (MASTER RECORDER ONLY)



ONE DEVICE NEEDED IN MASTER RECORDER ONLY.
OPERATION: DEVICE ERASES EVERY 16th PULSE SO THAT RECORDS MADE ON SLAVE RECORDERS CAN BE ALIGNED IN TIME WITH A RECORD MADE SIMULTANEOUSLY ON THE MASTER RECORDER.

FIG. 11 SCHEME FOR ERASING EVERY 16th PULSE

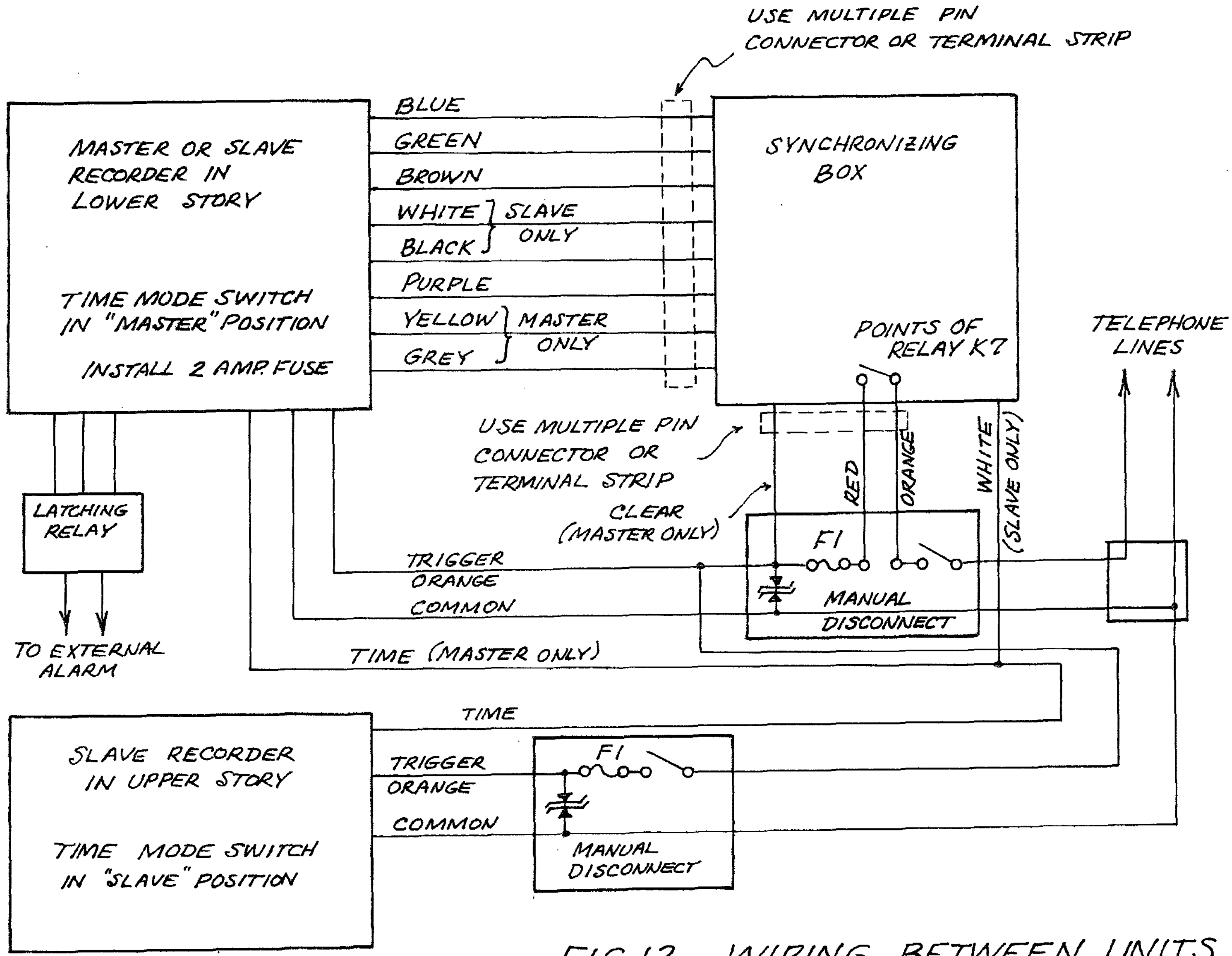


FIG. 12 WIRING BETWEEN UNITS